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The Effect of EU-ETS on Swedish industry's investment in carbon mitigating technologies

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Abstract

The European Union's Emissions Trading Scheme (EU-ETS) is so far the largest emissions trading system in the world. It covers about 12000 installations, representing approximately 45% of EU emissions of CO_2, with the objective to establish a carbon price creating incentives for cost efficient reductions of emitted green house gases. In this article we perform an ex-post analysis where we use detailed firm level data to analyse the effect of the EU ETS on firms' investment decisions in carbon reducing technologies. In addition we draw on the existing literature and control for firm specific characteristics that has previously been shown to be determinants of firms' investment in clean technology.

Key words: investment, technological adoption, clean technology, EU ETS, firm behavior, climate change, carbon

JEL classification: D21, O33, Q53

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Introduction

The European Union's Emissions Trading Scheme (EU-ETS) is so far the largest emissions trading system in the world. It covers about 12000 installations, representing approximately 45% of EU emissions of $CO_{2,}$ with the objective to establish a carbon price creating incentives for cost efficient reductions of emitted green house gases. The trading scheme has during its first two phases[1] attracted interest not only among scholars, but also among the public, and some characteristics of the scheme has been much debated (see e.g. Wråke et. al. 2012 for an overview of the most contentious issues surrounding the EU-ETS). The interest from scholars have resulted in a vast literature covering different aspects of the scheme such as allocation (primarily grandfathering vs auctioning) of permits (Cramton and Kerr 2002; Goeree et al. 2010) and the effect on the EU industry's competitiveness (Smale et al. 2006; Hourcade et al. 2007; de Bruyn et al. 2008). However, due to the relatively short time period the scheme has been in effect it has so far been difficult to do rigorous ex-post empirical analysis of the scheme, and much of the research up until now has been based on ex ante analysis of the scheme, or case studies primarily based on interviews. Two such studies are Rogge at al. (2011) and Hoffmann (2007) where the authors analyse the effect of the EU ETS on the German power sector. Both articles conclude that the price of allowances (carbon dioxide) are part of the current corporate decision making but they see limitations for the scheme regarding its ability to influence large scale investments and create incentives to adapt new technology corresponding to the EU 2050 targets.

In this article we aim to add to the ex-post evaluation of the EU-ETS by using detailed firm level data to analyse the effect of the scheme on firms' investment decisions in carbon reducing technologies. In addition we draw on earlier literature and control for firm specific

[1] Phase I: 2005-2007, and Phase II: 2008-2012.

characteristics that has previously been shown to be determinants of firms' investment in clean technology (Pizer et al. 2002; Anderson and Newell 2002; Kerr and Newell 2003; Gonzalez 2005; Millock and Nauges 2006; Askildsen et al. 2006; Hammar and Löfgren 2010).

The detailed information on type of investments on firm level makes our data both unique and well suited for the purpose of the paper, but there are still some limitations to our analysis; firstly our data covers the first and, only to some extent, the second phases of the EU-ETS. Secondly, the data covers only one country, Sweden, and hence our study needs to be complemented with studies on other countries that are part of the scheme to draw more general conclusions on the effect of EU-ETS on firms' investment behaviour.

The structure of the paper is as follows: Section 2 provides a thorough descriptive analysis and overview of the Swedish industry's investment in carbon dioxide reducing measures; this is followed by an introduction to the econometric analysis in Section 3, and a discussion of the variables we use in the analysis (section 4). In Section 5 we present and discuss the results, and in Section 6 we end with some concluding remarks.

Investment in carbon dioxide reducing measures

Our data covers all sectors in Sweden that were included in the EU-ETS[2] between year 2002 and 2008, and in addition some lagged data from years 2000 and 2001. For robustness check we also use data for five additional manufacturing sectors that were not part of the EU-ETS. Those are included in the analysis to control for non-observable factors that have changed

[2] We follow the EU ETS Directive (2003) for deciding which sectors to include in the ETS. According to the directive the trading scheme covers all refineries and coke oven, production of processing of ferrous metals, the mineral industry, the pulp and paper industry and all energy combustion units with a rated thermal input exceeding 20 MW. Hence the sectors in the analysis defined as EU-ETS sectors are the pulp and paper industry; refinery and coke oven industry; manufacture of mineral products; manufacture of basic metals; and the energy and heating sector.

over time and that could have affected investments decisions in both the ETS sectors and the non-ETS sectors.[3] In terms of total Swedish carbon dioxide emissions the five sectors included in EU-ETS stand for 35%. In comparison 33% of Swedish carbon dioxide emissions originate from transport and 13% from agriculture. The energy sector, with an emission share of 15%, stands out as the sector with the largest volume of carbon emissions compared to the other sectors included in the ETS. Then follows the metal industry sector (8%), the mineral industry sector (6%), refineries (4%), and last the pulp and paper sector (3%). The five control sectors contribute to 2% of total carbon dioxide emissions.

All data on carbon dioxide reducing investments is provided by Statistics Sweden from a yearly collection of firm level data on environmental protection investments between 2000 and 2008. The data is a random sample of the total population of firms and hence all firms are not represented every year (i.e. the data is unbalanced). The data on environmental protection investments is merged with other data on firm characteristics, also provided by Statistics Sweden. Overall, the dataset provides a detailed and high quality description of environmental protection investments and is undoubtedly the best available data for the analysis performed here.

The data provided from Statistics Sweden on environmental protection investments are separated into four categories: air, water, waste and remaining. Besides indicating the category of the investment made, the firms have made a short description of the investment. Using the description of the investments provided by the firms we identified investments aimed at mitigating carbon dioxide emissions (see Appendix 1 for examples of descriptions made by firms). These descriptions are only available from 2002 and since carbon mitigating

[3] The five control sectors are: manufacture of wood and wood products; manufacture of rubber and plastic products; manufacture of machinery and equipment; manufacture of fabricated metal products and manufacture of motor vehicles; trailers and semi-trailers.

investments is our dependent variable, the years prior to this can only be used for lagging explanatory variables.

When looking at the data on investments we found that over time there seem to be different patterns depending on the size of the investment. Hence, acknowledging that firms' investment behaviour can differ depending on the size of the investment (in particular; large investments have a longer pay back time and are of a more strategic character) we decided to distinguish between smaller and larger investments. Using the data on environmental protection investments aimed at mitigating carbon dioxide emissions, we created two dependent variables to be used in the econometric analysis regarding determinants for the decision to invest. Large investments are defined as investments larger than or equal to € 1 million per year, and small investment are defined as investments smaller than € 1 million per year. Correspondingly, the dependent variables used in the analysis are binary variables equal to one if an investment was made and zero otherwise.[4]

Figure 1 illustrates the percentage of small and large investments of total observations. From the figure it is clear that the investment pattern differs between large and small investments over time. In the figure we also added the control sectors (non-ETS sectors), and as can be seen the investment trend for small investments seem to be quite similar for the sectors included in the EU-ETS and those not included, indicating that there might be other factors explaining the probability to make smaller investments to reduce carbon dioxide than the trading scheme. Regarding the large investments the pattern is very different comparing the firms included in the ETS and those not included. For the non-trading sectors, large

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[4]Note, if a large investment was made this observation is dropped from the small investment sample. Hence, the dependant variable for the large investment is a binary variable equal to one if an investment larger than or equal to € 1 million was made and zero otherwise. For small investments the binary variable is equal to one if an investment less than € 1 million was made, zero otherwise, and if a large investment was made the observation is dropped.

investments have been zero almost the whole time period, which is expected since those sectors only stand for a small share of carbon dioxide emissions.

>>Figure 1.

The empirical analysis is based on a dataset consisting of 229 firms included in the ETS, with a total of 932 observations (see Table 1 row one and two. Note that the first column indicate whether the figure refers to number of *firms* or number of *observations*). The control sectors (non-ETS, see row three and four in Table 1) consists of 477 firms and 1626 observations. Accordingly, the analysis including both the ETS sectors and the non-ETS sectors involves 706 firms and 2558 observations (see row five and six in Table 1). 42 of the total 706 firms made at least one large investment, 113 firms made at least one small investment and 579 firms made no investment at all during the time period.[5] In our sample, 28 firms are both small investors and large investors. Among the 229 ETS-firms, 56 have made at least one small investment, 40 at least one large investment and 159 have made no investment at all. Correspondingly; among the 477 non-ETS firms, 57 have made an investment to mitigate carbon dioxide emissions whereof two firms made a large investment and 57 made a small investment. Hence, 420 firms in the non-ETS sectors made no investment at all during the time period 2002-2008.

>>Insert Table 1 here.

Large carbon abatement investments, above € 1 million, in the ETS sectors are dominated by biofuel investments (46%), district heating (25%), and energy efficiency investments (22%). For small investments below € 1 million, energy efficiency investments dominate with over half of the investments. Moreover, 23% of the investments are biofuel investments and 18% are district heating investments. As Table 2 demonstrates, the pulp and paper industry and the

[5] Note that a firm can make both small investments and large investments and is then classified both as a small investor and a large investor.

energy and heating sector stands out as the sectors with the highest share of large investors. These sectors also have a high proportion of small investors. However, for small investments, the pattern of investing firms is more evenly distributed among the sectors. The energy and heating sector has the highest share of firms making small investments, around 35%, while approximately 20% of the firms in the pulp and paper industry, the mineral industries and the metal industries made small investments. Regarding size of the investments; firms in the pulp and paper sector made the highest average investments, followed by the energy and heating sector, refineries, mineral sector and metal sectors. A corresponding table for the sectors not included in the EU-ETS (i.e. the control sectors can be found in appendix, Table A1).

>>Table 2.

Introduction to the econometric analysis

Our primary aim is to disentangle the effect of the introduction of the EU-ETS on the probability of firms investing in carbon reducing technologies (distinguishing between small and large investments). However, there are many aspects that make this a challenging endeavour. Firstly, while it is important to study the effect of the introduction of the EU-ETS on investment behaviour, there are certain debated characteristics of the scheme that we would like to disentangle; primarily the effect on investment behaviour of the marginal price of CO_2 (i.e. the EUA-price), and the effect of over-allocation of permits (i.e. that some firms received more permits than they had emissions). However, the data does not allow us to include these features before the introduction of the EU-ETS, since before the introduction there were no price on EUA, and no allocation of permits. One option would be to start with an analysis using a before-after strategy; i.e. including the introduction of the EU-ETS as a dummy from 2005 when the scheme was first implemented. However, if we only include a dummy to control for the ETS (and only for the firms included in the ETS) we cannot be certain that a potential effect is attributed only to the policy itself. Rather investment behaviour could be affected by economy wide shocks that we cannot control for, and such an analysis would assume that there absent of the policy change would be no change in average investment behaviour. One way to control for this is to use the difference-in-difference estimator. The difference-in-difference estimator allow us to compare outcomes before and after a policy change for a group affected by the change (the sectors/firms included in the ETS, the so called treatment group) to a group not affected by the change (the control group). However, we can only use the difference-in-difference estimator to analyse the effect on small investments since there are very few (2!) observations of large investments in the control group. Also, an important assumption when using the difference-in-difference estimator is that the policy should not have been known before hand. In our case the decision to implement the ETS was known before 2002 (European Commission 1998 and 2001), which means that the difference-in-difference estimator could be confounded. A potential solution to this type of problem is to focus the analysis on the time the policy became publically known instead of when it was implemented. But since there is no available investment data ex ante 2002 this is unfortunately not an option.

For the large investments we have an additional problem that we have no control group to compare with and also most large investments have long planning horizons and our data only covers seven years.

In response to the caveats outlined above our econometric strategy will be to run different model specifications and estimation methods to see if the main results are overall robust. We perform the main analysis in two stages for the small and large investments respectively. The first stage for both types of investments has the purpose of isolating the effect of the implementation of the scheme (also controlling for observed firm characteristics). The second step focus on the years when the trading scheme has been in effect (2005-2008). However, as mentioned above, our model is potentially too short run to be well suited to explain the large investment behavior of the firms.

To summarize, the analysis of the introduction of the EU-ETS on *small* investments consists of:

1. Running a difference-in-difference estimation for the period 2002-2008 (all sectors included), to analyse the effect of the ETS on the probability of making small investments both with and without controlling for firm specific characteristics.
2. Running a model for the period 2005-2008, with ETS-specific variables, only including the ETS-sectors.

The analysis of the effect of the introduction of the EU-ETS on *large* investments consists of:

1. Running a before-after difference estimation to analyse the effect of the ETS on the probability of making large investments, controlling for firm specific characteristics (for the period 2002-2008). The analysis only covers sectors included in the ETS.
2. Running a model for the period 2005-2008, with ETS-specific variables, only including the ETS-sectors.

All estimations are done using random effects logit models with sector as panel level. Further, as robustness checks we run random effects models applying maximum likelihood, nested both in sector and firms (for the period 2005-2008), with ETS-specific variables, only including the ETS-sectors as well as ordinary least square regressions.

Below follows a description of the explanatory variables used at different stages in the analysis, including a short discussions of the expected effect of the variables on the investment decision.

The explanatory variables

Variables related to the EU ETS

The carbon dioxide price: The EUA price and carbon dioxide tax

The data for EUA-prices is provided by PointCarbon (www.pointcarbon.com). They obtain closing prices reflecting the best bid and offer at the end of every trading day. Prices are available both for spot and forward trading. In the analysis we use yearly averages for spot prices from December previous year until December current year since EUAs are due December every year. However, the carbon dioxide tax, implemented in 1991, was not abolished for the sectors included in the EU-ETS and therefore we create a variable which sums the EUA-price with the carbon dioxide tax[6] which hence reflects the full the carbon dioxide price. For the industry sector, during 1998-2008, the carbon dioxide tax has been around € 20 per tonne emitted carbon dioxide (Riksrevisionen, 2009). The yearly average price for emitting one tonne of CO_2, adding the carbon dioxide tax with the price for one EUA is plotted in Figure 2 (for firms included in the ETS). Before the start of the EU-ETS the cost for emitting one tonne of carbon dioxide was stable slightly above 20 €. After the introduction of the trading scheme, the price for emitting one tonne of carbon dioxide has approximately doubled (due to the additional EUA price), except for a sharp decline 2007 when the EUA price moved toward zero in the end of 2007.[7] An increase in the price of carbon dioxide is expected to affect the decision to invest positively, but as can be seen already from the descriptive analysis of the data, price on carbon dioxide and small investments does not seem

[6] Accounting for the carbon dioxide tax exemptions for the industry sector. However, district heating are not exempted from the carbon dioxide tax, and based on the energy situation 2007 in Sweden where heating consumption was 27 % of total heating consumption and electricity consumption, we assume that the energy sector on average pay 27 % of full carbon dioxide tax.

[7] The reason for the price drop was according to Alberola et al, (2007), the announcement that verified emissions were below allocated allowances. Banking of the allowances between phase I and phase II was not allowed, which may also have contributed to the price decline.

to have a general positive correlation (rather carbon dioxide price is negatively correlated with small investments for the sectors included in the ETS, while it is positive for the large investments), and hence this is an indication that it is likely that we will not find a significant positive effect in the econometric analysis.

>>Figure 2.

Over allocation

Unfortunately due to confidentiality, it is not possible to convert firm level data on allocation of allowances to our dataset. Therefore, the variable for over-allocation is estimated annually per sector. Despite this, we believe that the sector's average of allocation of allowances in relation to its emissions captures an important measure of the firms average windfall profits. A surplus of allocated allowances could have a positive effect on investments since it implies that the firm has more resources to invest in new technology. On the other hand the firm might act strategically by keeping their emission level high to continue to receive permits (see e.g. Malueg, 1989 and Milliman and Price, 1989). The Swedish Environmental Protection Agency provides yearly summaries over the allocation of EUAs and the emission of carbon dioxide of Swedish sectors' participating in the ETS. From these we calculate over-allocation quotas through the following formula:

$$Overallocation = \frac{\text{Allocation of allowances per sector} - \text{Total emission per sector}}{\text{Allocation of allowances per sector}}$$

Other observed firm characteristics – control variables

The data on firm level is provided from Statistics Swedish and all price data is converted to euro using yearly average exchange rate from Statistics Sweden[8].

Learning by doing

Firms' expenditure on green R&D is used as a measure of the firm's environmentally related internal knowledge. We argue that engagement in green R&D does not only affect the invention of new technologies but also the probability of making an investment in new already existing technologies. Hence, deeper technological knowledge which is provided from undertakings in green R&D leads to further adoption of new technology. The effect of green R&D on firm's adoption of new technology has been empirically examined by e.g. Hammar and Löfgren (2010), and Frondel et. al (2004). Both studies find that engaging in green R&D has a positive impact on the probability that a firm adopts new technology. In the analysis we include a lagged binary variable for green R&D[9]. The variable is lagged partly to avoid problems with endogeneity between green R&D and the adoption decisions, and partly because of the potential time lag between green R&D expenditures and the decision to invest. We also include a dummy variable that is equal to one if the firm has expenses on environmental administration, education or information. Having an environmental prioritization within the firm is expected to positively affect green investments.

We also control for earlier investments (the firm's environmental protection investment previous year, i.e. the total investment to air, water, waste and other). We argue that if the firm has made an environmental protection investment in an earlier time period it has a higher probability of investing the current time period, based on the complementary aspect of learning by doing. We also control for the potential presence of crowding out effects or

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[8] 2002: € 1 = 9.16 SEK, 2003: € 1= 9.13 SEK, 2004: € 1 = 9.13 SEK, 2005: € 1= 9.28 SEK, 2006: € 1= 9.25 SEK, 2007: € 1 = 9.25 SEK, 2008: € 1 = 9.61 SEK, http://www.scb.se/Pages/TableAndChart____32240.aspx

[9] Since expenses on R&D are missing for non-ETS firms for year 2001, R&D is not lagged for year 2002 for the non-ETS sectors.

substitution effects between investments aimed at carbon and other categories of investments by including a dummy variable equal to one if the firm has made another environmental protection investment not aimed at air but at waste, water or other the same year.

Fuel use and price

The average price on fuel, in particular fossil fuel price, can affect the decision to adopt new technologies. However, there is a clear correlation between the world market price of oil and the EUA price. Figure 3 describes the price of oil between 2000 and 2010 and the EUA price between 2005 and 2010.[10] Except for the fall in EUA prices due to a chock in April 2006 when reported emission data for 2005 indicated an over allocation of permits, and the following decline in EUA prices 2007 due to the inability to bank permits between phase I and phase II, the oil price and the EUA price has co-varied to a high degree. We therefore have potential multicollinearity problems if including both the carbon dioxide price and the price of e.g. oil in the analysis. To avoid multicollinearity problems and at the same time account for the importance of fuel price variation to firms we include a variable capturing the firm's fuel intensity (instead of price of fuel): the ratio between energy use and revenues. Maynard and Shortle (2001) include an energy intensity variable to determine adoption of abatement technology and find that this variable has a positive and significant impact on abatement investments. Hence, firms with high energy intensity have more incentives to reduce its energy dependency than firms with low energy intensity. We also control for which type of fuel the firm use. The fuels are separated into either fossil fuel or biofuel. Fossil fuel consists of fossil oils, gasoline, fossil gas, coal, coke-oven coke and diesel. Biofuel consists of wood fuel, peat, waste and black liquors. However, there is a risk that this variable suffers from endogeneity problems since investment in abatement technology will decrease the use of

[10] The yearly average oil price is collected from the U.S Energy Information Administration, EIA and converted from nominal U.S dollars per barrel to real euro per barrel, using average annual exchange rate and average annual U.S inflation. We also tested with the natural gas price instead of the world market oil price. These two prices follow each other almost one-to-one, the correlation is 0.94.

fossil fuels. To avoid this problem, we include the firm's average fuel intensity the two years before our researched time period, 2000-2001[11]. High fossil fuel intensity may lead to higher abatement investments since the firm has incentives to invest given the opportunity to profit on the investment. High biofuel intensity on the other hand can both be seen as measure of the firms' historical ability to invest in biofuel which means that it could be expected to have a positive impact on investments, but it could also be an indication of that firms already invested in cleaner technology which makes the expected effect ambiguous.

>>Figure 3.

Other firm characteristics

We include wages in our model to control for the possibility that environmental investments are affected by the firm's capital capacity. The higher input prices a company can endure, the more they might be able to spend on abatement technology. Higher wages could also have a negative relationship with abatement technology, since wage expenses might crowd out abatement expenditure. Wages is created as the ratio between the firm's total expenses on wages with the number of employed.

Revenues are used as a measure of the firm's size in billion euros. There is a possibility that larger firms have more access to knowledge and capital and therefore a higher probability of adopting new technologies. On the other hand, large firms may face more barriers than smaller firms when it comes to decisions about technology adoption. Firm size has in earlier empirical technology adoption studies had a significant positive impact on the decision to adopt new technology, see for example Hammar and Löfgren (2010), Frondel et al (2004), and Kerr and Newell (2003).

Other Swedish environmental policies

[11] If the value is missing for one year it is replaced with the other year's observation. To avoid losing observations we replace the variable with the sector's average fuel intensity 2000-2001 if both values are missing.

The aim of this analysis is to isolate the effect of the EU's trading scheme. It is therefore important to control for other environmental policies that may affect investments in carbon mitigation. Electricity certificates as well as investment programs can affect investments in carbon dioxide mitigation measures but since no data is available on these policy instruments (that we can merge with our firm level data) we cannot control for these policies directly, rather these policies are captured by controlling for sector in the estimations. Table 3. gives a summary of the variables used in the analysis.

>>Table 3.

Average characteristics for investors and non-investors included in the ETS are summarized in Table 4. On average, firms that made an investment to mitigate carbon emissions are larger than non-investing firms. Furthermore, investors have a higher rate of expenses on green R&D, have made larger green investments previous years and have made more other environmental protection investments not aimed at air emissions. Fuel use, both fossil fuel and biofuel consumption, is higher among investors compared to non-investors. Comparing large investors with small investors, firms that have made a large investment are bigger, have higher average wages, have made larger investments earlier year and have more often had expenses on green R&D.

Descriptive statistics for investors and non-investors in the non-ETS sectors are presented in Table 5. On average investing firms in the non-ETS sectors are larger than non-investing firms, have made higher investments to protect the environment previous year and have more often had expenses on green R&D. In contrast to the ETS sectors, fossil fuel and biofuel intensity is higher in the non-investing companies compared to the investing companies.

Comparing ETS-firms with non-ETS firms, trading firms have a higher investment mean, both for large investments and small investments, and ETS-firms have more often made an investment to mitigate carbon emissions than the firms that are not part of the scheme. ETS-firms are also on average larger, have made larger earlier environmental protection investments, have made more environmental protection investments to water, waste and other and have more often expenses on green R&D. The ETS sectors are also more energy intensive, both biofuel use and fossil fuel use is higher in the ETS sectors, when compared to the non-trading sectors.

>>Table 4 and Table 5.

Econometric Analysis and Results

As outlined in the introduction to the econometric analysis we are going to perform the analysis in two stages for the small and large investments respectively. The first stage for both types of investments has the purpose of isolating the effect of the implementation of the scheme (also controlling for observed firm characteristics). The second step focus on the years when the trading scheme has been in effect (2005-2008) and here we add EUA price (as part of the total carbon dioxide price) and the variable capturing over allocation. The results (marginal effects) are presented in Table 6.

The effect of the introduction of the EU ETS on the probability of firms making a small investment in carbon reducing technologies

As can be seen the difference-in-difference estimation reveal that there is no significant effect of the implementation of the ETS on the (small) investment behaviour of firms included in the scheme. However, in the first estimation presented in Table 6 (in which we do not include the control variables) there is both a significant positive time effect as well as a significant positive effect for the ETS sectors (i.e. a treatment group effect) on the probability of making an investment. During the period after the implementation of the scheme the probability to make a small investment is 2.4 percentage point higher both for firms included in the ETS as well as firms not included in the ETS compared to before the implementation. Also, the probability to make a small investment is 4.9 percentage points higher if the firms are included in the ETS compared to the sectors that are not included (which is due to permanent differences between the sectors included in the ETS and those not included). Still, as noted above we do not find any true causal effect of the implementation of the scheme. When we add the control variables the positive effect of the ETS sectors disappears which are expected since the control variables captures firm and sector specific characteristics.

When we look at the time period 2005-2008, only including the ETS-sectors, we do not find any significant effect of neither the carbon dioxide price nor any effect of over allocation of permits on investment behaviour.

Regarding the control variables our results show that green R&D is insignificant for the probability of making a small investment. However, the investment behavior is affected positively by earlier environmental protection investments as well as investments made during the current year (aimed at waste, water or other). Hence, there seem to be a complementary aspect of learning by doing, and we do not find any support for crowding out effects or substitution effects between investments aimed at carbon and other categories of investments.

For the other control variables the signs are as expected and consistent over the different model specifications but significance differs. Fuel use is positively significant; bio fuel use for the time period 2002-2008 (including both EU-ETS sectors and non EU-ETS sectors) and fossil fuel use for the 2005-2008 period (only including the ETS sectors). Firm size and wages are significant for the 2005-2008 period, and administration (i.e. if the firm has expenses on environmental administration, information or education) is significant only in the difference-in-difference estimation covering the years 2002-2008.

Robustness checks

Using different model specifications and estimation methods we find that the main results are overall robust. The results are qualitatively the same also when estimating the models with ordinary least square regressions as well as when estimating more advanced multilevel latent variable models (nested both in the sector and firm level).[12]

[12] The results are available from authors upon request. The procedure GLLAMM (Generalized Linear Latent And Mixed Models) in the statistics software STATA/SE 12.0 was used for the multilevel estimations.

Also, in the analysis we control for the "full" carbon dioxide price, but one could argue that we should divide the price variable into one EUA-part and one carbon tax part. One reason could be that firms treat the prices as two different decision variables. If we do that we find that both the EUA price and the carbon tax have significant effects on the probability of making a small investment in carbon reducing measures, but the EUA price has a (unexpected) negative significant effect and the carbon tax has a (expected) positive significant effect on the probability of making a small investment. If we believe that it is accurate to divide the price variable in two parts then one reason for the EUA price to have a negative significant effect on investment behaviour could be that this price has been subject to large uncertainty for the firms during the period, while the carbon price has been a more certain policy instrument. However, this is highly speculative, and warrants more research.

We could also have included the (total) carbon dioxide price in the first stage of the analysis (the difference in difference estimator) since there was a carbon tax prior to the implementation of the ETS. Doing that does not change the result for small investments; hence the carbon dioxide price is insignificant and does not alter the other results presented in Table 6.

The effect of the introduction of the EU ETS on the probability of firms making a large investment in carbon reducing technologies

The before-after estimation of the probability of firms' making a large investment in carbon reducing technologies reveals that the implementation of the ETS did not affect firms' investment behaviour. Nor did the analysis of the period 2005-2008 show any significant effect of the scheme through carbon dioxide price and over allocation. However, the results for large investments should be interpreted with care, as it seems as our model and the included variables are not well suited to explain the investment behaviour for investments over 1 million Euros. Hence, while the robustness checks corroborate our results (using different estimation methods) it should still be said that such large investments need a longer time period to be analysed correctly.

However, it should be noted that when the price of carbon dioxide is included in the before-after estimation then the price becomes significant for the large investments. The price is also very close to being significant in the analysis of the period 2005-2008.

The effects (signs) of the control variables are as expected and consistent over the different model specifications but significance differs. In particular green R&D is significant in the before-after estimation covering the years 2002-2008 and as for the small investments earlier investment (learning by doing) is of importance. Higher fuel use also affects the probability of investing in carbon reducing technologies and there is no indication of crowding out from other environmental protection investments.

>>Table 6.

Concluding Remarks

In the analysis we distinguish between large and small investments, and our results show that the introduction of the EU-ETS does not seem to have had a significant effect on firm investment decisions in carbon dioxide reducing measures. Rather, the decision to make *large* investments seem to be determined primarily by firm characteristics such as the energy intensity of the firm's production, earlier investment in green R&D and earlier investments related to the environment. For *smaller* investments, basically the same firm characteristics are of importance, but again, we do not find any significant effect of the EU-ETS per se. We would have expected that the probability to invest in carbon reducing technologies should increase due to the introduction of the ETS, so are there any explanations for our findings?

First of all, the cap of the EU ETS has been very generous during the first phases (and still is), and this naturally affects incentives to invest in carbon dioxide reducing measures negatively, since a generous cap translates into a low carbon dioxide price. Secondly, the positive and significant time effect (on small investments) could very well be explained by only overall economy wide changes, but the implementation of the scheme also created information and signaling effects which could have affected firm behavior outside the scheme. However, our current data does not allow us to make a thorough analysis of this aspect but we believe this could be interesting future research.

A final note need to be made regarding the large investments where we believe that the time period is most likely too short to draw any final conclusions due to those investments longer decision times.

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Appendix 1

Examples of descriptions filled in by firms:

Bio fuels

- *Reconstruction of oil pan to biofuel pan, equipment for handling biofuel, purification filter for chimney gas and renovation of turbine for own production of green electricity.*
- *Conversion of coal heat pan to biofuels*
- *New biofuel pan with the best environmental technic*
- *Start heating of bio oil*

District heating

- *Conversion of electricity/oil heating to district heating with over 95 % renewable energy*
- *District heating culvert (replacing oil with district heating)*
- *Recovery of heat project*
- *District heating, replacing heating oil*

Switch to other energy source

- *Upgrading of firing furnace and transfer from light oil to gas oil*
- *Increased share of alternative fuels, for example tires. Replaces fossil fuels. Recycling of chimney gas for heating coal plant. Replaces oil*
- *Transition from gas oil to natural gas for heating*

Energy efficiency

- *Investment in new process equipment for higher effectiveness. the purpose is both productivity and the environment*

- *Waste heat boilers installed for rest heat recycling*
- *Investments in chimney gas condensation*
- *New steering of steam pan*

Table A1. Investing firms, Non-ETS sectors

	Non-investors (%)	Investors (%)	Small investors (%)	Large investors (%)	Mean investment (1000 €)*
Wood industries	91	9	9	1	195
Rubber and plastic industries	94	6	6	0	98
Fabricated metal industries	87	13	13	0	144
Machinery and equipment industries	88	12	12	0	125
Motor vehicles industries	83	17	17	1	155
All Non-ETS sectors	88	12	12	0.4	142

*If the firm has made an investment >0 .

Tables and figures to be inserted in the main text

Figure 1. Share of small and large investments of total observations, by year, ETS-sectors and non-ETS sectors

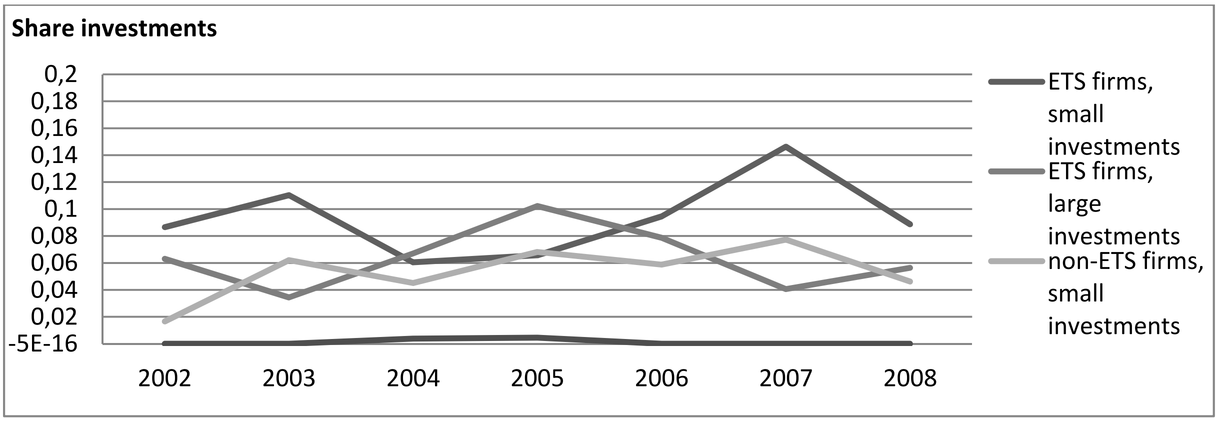


Table 1. Number of investors and non-investors (2002-2008).

	Non investors	Investors	Total	Small investors	Large investors
ETS No. of firms	159	70	229	56	40
ETS No. of observations	787	145	932	86	59
Non-ETS, No of firms	420	57	477	57	2
Non-ETS, No. of observation	1538	88	1626	86	2
Total no. of firms	579	127	706	113	42
Total no. of observations	2325	233	2558	172	61

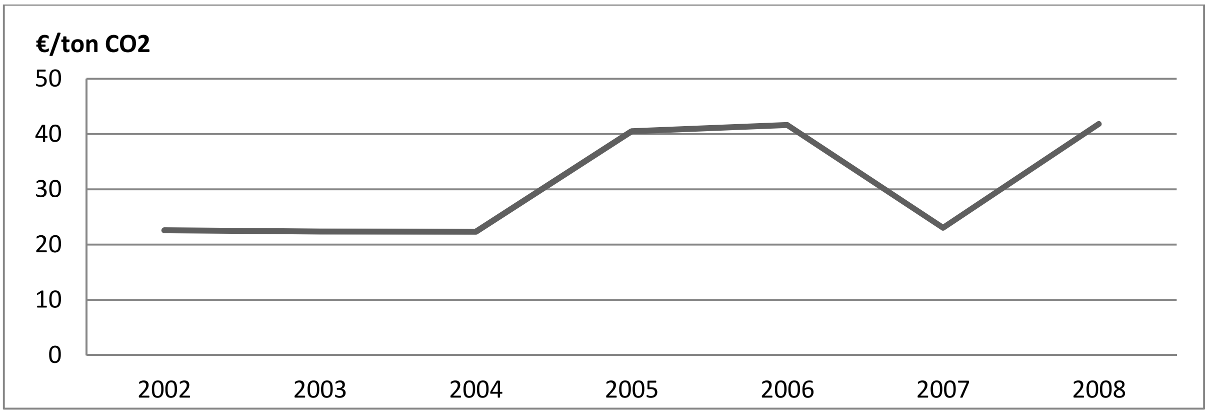
Table 2. Share of investing firms by sector (2002-2008).

	Non-	Investors (%)	Small	Large	Mean

	investors (%)		investors (%)	investors (%)	investment (1000 €)*
Pulp and paper industry	63	37	21	21	2227
Refineries	92	8	0	8	914
Manufacture of mineral products	82	18	18	11	876
Manufacture of basic metals	20	80	19	6	513
Energy and heating sectors	45	55	35	31	2007
All ETS sectors	53	47	24	17	1788

*If the firm has made an investment >0 .

Figure 2. The industry's total price for emitting one tonne of carbon dioxide: the carbon dioxide tax summed with yearly average EUA price.



Source: Point carbon, Swedish Tax Agency, Swedish Environmental Protection Agency and Swedish Energy Agency, own calculations.

Figure 3. World market spot price of oil and EUA. Oil price measured in €/Barrel, EUA price measured in €/EUA.

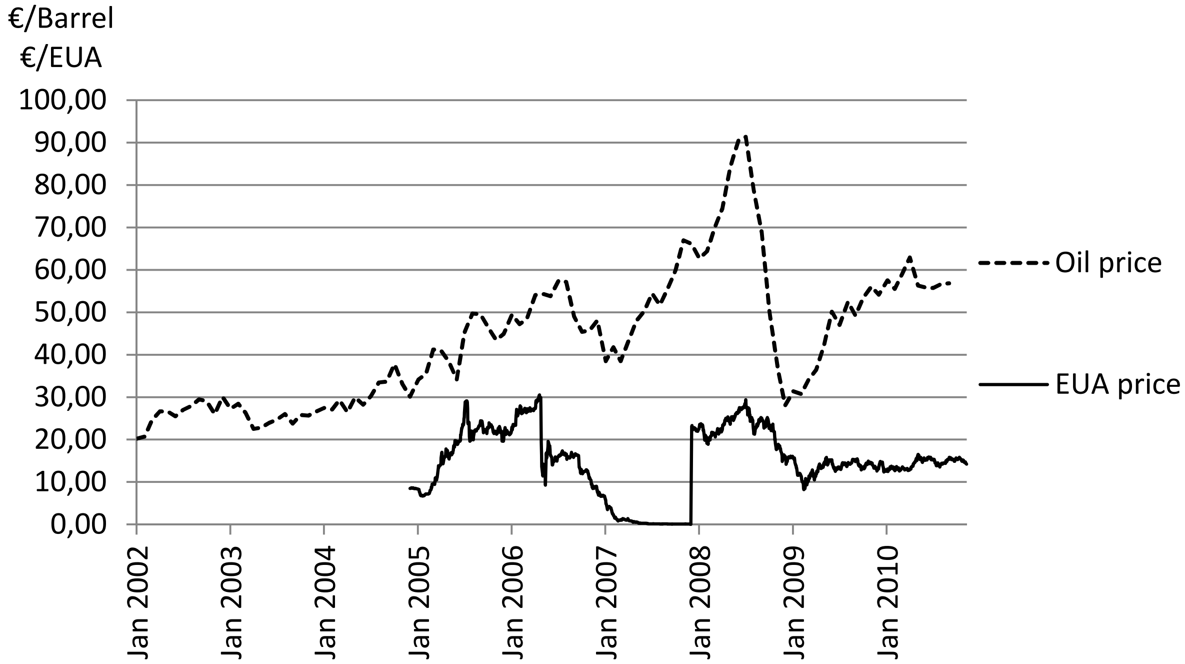


Table 3. Variable description

Variable	**N**	**Description**
Large investment	932	=1 if the firm has made an investment equal to or above € 1 million, otherwise zero.
Small investment	877	=1 if the firm has made an investment below € 1 million, otherwise zero.

Over allocation	932	Over allocation or under allocation, percentage per sector and year
Carbon dioxide price	932	The yearly average price for one EUA, based on current year's spot price, € /ton CO_2 plus the yearly average Swedish carbon dioxide tax, € /ton CO_2
Oil price	932	Yearly average oil price, €/barrel
Firm size	932	Revenues, €*10^9.
Wages	932	Average salary per employee and year, € 1000
Earlier investment	932	The firms previous year's total environmental protection investments (air, waste, water and other) normalised with revenues, € 1000
Green R&D (lagged)	932	=1 if the firm had expenses on green R&D previous year
Administration	932	=1 if the firm has expenses on environmental administration, information or education, otherwise zero
Fuel intensity: Fossil fuel use	932	The firm's average fossil fuel use in relation to revenues 2000-2001, GJ/€
Fuel intensity: Bio fuel use	932	The firm's average bio fuel use in relation to revenues 2000-2001, GJ/€
Other investment	932	=1 if the firm has made another environmental protection investment to waste, water or other.

To control for inflation, the following variables are expressed in real values: EUA-price, carbon dioxide tax, oil price, firm size, wages, earlier investments and electricity certificates.

Table 4. Descriptive Statistics for ETS sectors

Variable	All				Non-investors				Small investors				Large investors			
	Mean	*Std.*	*Min.*	*Max.*	*Mean*	*Std.*	*Min.*	*Max.*	*Mean*	*Std.*	*Min.*	*Max.*	*Mean*	*Std.*	*Min*	*Max*
Large investment	0.063		0	1	0	0	0	0	.12		0	1	0.30		0	1
Small investment	0.099		0	1	0	0	0	0	0.33		0	1	0.32		0	1
Firm size	0.21	0.33	0.00073	3.09	0.14	0.21	0.00073	1.60	0.32	0.49	0.014	3.09	0.37	0.51	0.013	3.09
Wages	37.0	8.34	7.88	109.3	36.5	9.03	7.88	109.3	37.1	7.35	17.6	73.3	39.6	7.32	28.4	73.3
Earlier investment	0.0104	0.036	0	0.65	0.0044	0.015	0	0.18	0.017	0.056	0	0.65	0.032	0.069	0	0.65
Green R&D	0.307		0	1	0.209		0	1	0.44		0	1	0.57		0	1
Administration	0.84		0	1	0.81		0	1	0.89		0	1	0.89		0	1
Fossil fuel use	0.0049	0.012	0	0.12	0.0048	0.013	0	0.12	0.0049	0.0088	0.000031	0.063	0.0065	0.011	0.000078	0.063
Bio fuel use	0.0080	0.012	0	0.062	0.0055	0.010	0	0.047	0.011	0.014	0	0.062	0.013	0.014	0	0.059
Other investment	0.59		0	1	0.48		0	1	0.79		0	1	0.78		0	1

Table 5. Descriptive Statistics for Non-ETS sectors

Variable	All				Non-investors				Small investors				Large investors			
	Mean	*Std.*	*Min.*	*Max.*	*Mean*	*Std.*	*Min.*	*Max.*	*Mean*	*Std.*	*Min.*	*Max.*	*Mean*	*Std.*	*Min*	*Max*

Large investment	.0012		0	1	0	0	0	0	.0064		0	1	.17		0	1
Small investment	.053		0	1	0	0	0	0	.28		0	1	.30		0	1
Firm size	.16	.67	.0010	9.6	.13	.66	.0010	9.6	.29	.71	.0066	5.07	2.3	2.1	.13	5.07
Wages	34.7	10.6	16.3	229.4	34.5	11.1	16.3	229.4	35.5	7.72	22.3	88.4	38.5	8.6	28.3	51.4
Earlier investment	.0014	.0089	0	.30	.0012	.0097	0	.30	.0020	.0044	0	.033	.0014	.0020	0	.0068
Green R&D	.12		0	1	.11		0	1	.19		0	1	.58		0	1
Administration	.75		0	1	.71		0	1	.89		0	1	.83		0	1
Fossil fuel use	.00024	.00043	0	.0093	.00025	.00046	0	.0093	.00023	.00027	0	.0013	.00016	.00011	0.000060	.00026
Bio fuel use	.00045	.0014	0	.010	.00049	.0015	0	.010	.00030	.00090	0	.0044	.00026	.00028	5.05e-09	.00053
Other investment	.35		0	1	.30		0	1	0.56		0	1	0.75		0	1

Table 6. Marginal effects based on the estimations of random effects logit models with sector as panel level, binary dependant variable: investment (small investment<1 million euros, large investment>1 million euros).

	Small investments			Large investments	
Variable	**Diff-in-diff (year 2002-2008)**	**Diff-in-diff (year 2002-2008) with controls**	**Only ETS-sectors (year 2005-2008)**	**Before-after, only ETS-sectors (year 2002-2008)**	**Only ETS-sectors (year 2005-2008)**
IntroETS	0.024*	0.025**		0.013	
	(0.0131)	(0.0111)	-	(0.0125)	-
ETS sector	0.049**	0.003			
	(0.0236)	(0.0145)	-	-	-
IntroETS* ETS sector	-0.011	-0.011			
	(0.0167)	(0.0139)	-	-	-
Over allocation			0.001		-0.005
	-	-	(0.0139)	-	(0.0092)
Carbon dioxide price			-0.002		0.002
	-	-	(0.0013)	-	(0.001)
Oil price	-	-	-	-	-
Firm size		0.004	0.051**	0.032**	0.017
	-	(0.0050)	(0.0263)	(0.0150)	(0.0255)

Wages		-.001	-0.004**	-0.000	0.001
	-	(0.0005)	(0.0017)	(0.0009)	(0.0012)
Earlier investment		0.235**	0.366*	0.332**	0.182
	-	(0.1129)	(0.1921)	(0.1364)	(0.1431)
Green R&D (lagged)	-	0.012	0.019	0.029*	0.032
		(0.0109)	(0.2397)	(0.0173)	(0.0228)
Administration	-	0.030***	0.037	0.004	0.003
		(0.0093)	(0.0253)	(0.0180)	(0.0274)
Fossil fuel use	-	0.523	1.970*	0.591	1.463*
		(0.3738)	(1.1213)	(0.4465)	(0.8701)
Bio fuel use	-	1.635***	1.607	1.450**	1.583**
		(0.5003)	(1.2018)	(0.6806)	(0.6277)
Other investment	-	0.065***		0.004	0.004
		(0.0109)	0.103**	(0.0140)	(0.0203)
			(0.0329)		
Log likelihood	-613	-566	-135	-196	-115
Likelihood-ratio test of rho=0[1]	5.25**	0.01	1.00	0.40	0.00
No. of obs.	2497	2497	475	932	511

No. of sectors.	10	10	5	5	5

Note: All models include a constant.

*, **, *** denote that the coefficient is statistically significant at the 10%, 5%, and 1% levels, respectively.

[1]Where rho is the proportion of the total variance contributed by the panel-level variance component